WAVE BREAKING AND DISSIPATION IN THE NEARSHORE

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LONG-TERM GOALS

The long range goal is a predictive understanding of the spatial and temporal variability of wave breaking in the nearshore, and the impact of wave breaking on the forcing of mean and oscillatory flows, sediment transport, and changes in large scale nearshore morphology.

OBJECTIVES

(1) Improved modeling of wave transformation, wave breaking distributions, and surface wave stress on barred bathymetry

(2) Improved understanding of the forcing of infragravity waves by modulations in wave breaking patterns, and the cross-shore variation of infragravity wave motions across the surf zone

(3) Pilot measurements of wave breaking on the inner shelf

APPROACH

The difficult problem of understanding wave dissipation in the nearshore has been primarily approached through field observations made across a variety of beach profiles and under a wide range of wave conditions. Data are obtained remotely from video recordings of the surf zone and inner continental shelf, and image processing techniques are used to detect and quantify wave breaking over spatial and temporal scales ranging 10-1000 meters and 10-10000 seconds. The observed spatial distributions of ensemble-averaged wave breaking distributions are used to improve numerical dissipation estimates, and subsequently applied to parametric models of incident wave energy transformation and mean current forcing within the surf zone. The forcing of low-frequency oscillatory motion through spatial and temporal variations of the point at which a wave breaks is being approached through a combination of theory and observation. The relationship of wave breaking to sediment transport is being pursued through co-located video observations and collaborative *in situ* measurements of sediment concentration, turbulence, and void fraction (air concentration).

WORK COMPLETED

We have incorporated observations of wave breaking distributions into numerical models which include energy flux gradients from wave rollers (Duncan, 1981; Svendsen, 1984) and wave dissipation described by surface shear stresses. This has led to improved prediction of the transformation of wave energy (Lippmann, *et al*., 1996), the spatial variation of wave breaking (Lippmann and Thornton, submitted), and the relationship of observed wave asymmetry to wave breaking (Lippmann, *et al*., submitted) in the surf zone across arbitrary profiles. The modeled wave breaking distributions (verified with observations) have further been applied to model longshore currents (Reniers, *et al*., submitted; Faria, *et al*., in press). Ongoing theoretical work addressing the generation of edge waves in shallow water by spatial and temporal variations the point at which a wave breaks has also been completed (Lippmann, *et al*., 1997).

We have also participated in a field experiment in the spring of 1996 (MBBE), collaborative with the Naval Postgraduate School and the University of British Columbia. Observations of wave breaking on a gently sloping beach in Monterey Bay were obtained simultaneously with measurements of mean wave pressure and water level spanning the surf zone, and point measurements of velocities, sediment concentration, and void fraction ((PI's Thornton, Stanton, and Farmer)

Measurements of wave breaking on the inner shelf have been obtained from shipboard mounted video cameras oriented to view wave breaking within a few swell wavelengths of a directional wave buoy. A mechanical, gyro-stabilized video system was deployed aboard the R/V Cape Hatteras during the SandyDuck experiment and oriented to image the whitecapping in the vicinity of a moored directional wave buoy and an array of bottom mounted pressure sensors in 20 m depth off the coast of North Carolina (P.I. Herbers). Initial observations confirm the strong correspondence between the occurrence and orientation of individual whitecaps and the presence of swell crests (e.g., Donelan, *et al*., 1972).

Recently, continuous observations over a 3 month period of wave breaking were obtained as part of the SandyDuck field experiment held in the summer and fall of 1997. The spatial and temporal variations in the breaking wave field in and near the surf zone were quantified with an array of shore mounted daylight and intensified (night-time) video cameras mounted on towers of varying height. The relationship of breaking variability to the distribution of longshore currents, set-up, suspended sediment concentration, and ripple fields in relation to the offshore sand bars in the surf zone and the whitecapping on the inner shelf, will be examined collaboratively in detail with SandyDuck participants. Large-scale aerial over-flights used to measure the very large length scales of nearshore sand bars over the 100 km between Cape Hatteras and Cape Henry around the SandyDuck field site will be used to place the observations of nearshore morphological changes at the SandyDuck field site in context of the larger scale variability (sponsored by the U. S. Geological Survey, Co-P.I.'s Sallenger and Haines).

RESULTS

By incorporating the concept of the wave roller or whitecap (an elevated body of turbulent water supported along the face of the wave) into the wave energy flux balance, and further describing the dissipation of wave energy by the surface shear stress at the wave/roller interface, we have reduced the number of free parameters needed to describe the transformation of incident wave energy to one (Lippmann, *et al.*, 1996). The well-modeled wave transformation can then be input into a second model to well describe the spatial variation of ensemble averaged wave breaking distribution (Lippmann, *et al.*, submitted). The substantial improvement in the prediction of the observed wave breaking patterns leads to a better estimate of the spatial variation of the surface shear stresses and production of turbulence at the water surface produced by wave breaking. In particular, the successful modeling of the propagation of broken waves and bores into and across the bar trough is necessary to correctly estimate the spatial forcing for both set-up and longshore currents (Reniers, *et al.*, 1996; Lippmann, *et al.*, 1996). The advection distances of wave rollers is found to depend on the wave asymmetry and water depth, with greater propagation distances associated with less-steep waves and higher tidal periods. The measured wave skewness and asymmetry across the barred profile is spatially coincident with the observed breaking distributions (Lippmann, *et al.*, submitted).

Spatial and temporal oscillations, on the order of wave groups, in the amplitude of breaking waves produce modulations in radiation stress gradients with similar time and length scales. For a theoretical bi-chromatic wave field, the growth rate of resonant edge waves can be predicted, and is found to produce edge waves of the same amplitude of the incident waves on the order of 2-10 edge wave periods (Lippmann, *et al.*, 1997). A simple parameterization of the damping has edge wave e-folding time scales of 10-20 edge wave periods. Because the forcing is dominated by cross-shore gradients associated with both broken and non broken waves within the region of fluctuating surf zone width, a first order estimate of the forcing can be obtained from observations of the spatial and temporal variations of the locations at which a spectrum of waves break.

A cross-shore array of 9 co-located pressure sensors and bi-directional current meters from the 1990 Delilah experiment (P. I. Thornton), extending from the shoreline to approximately 4.5 m depth, were used to estimate the relative contributions of gravity waves and instabilities of the longshore current (shear waves) to motions in the infragravity band (Lippmann, *et al.*, submitted). Outside the surf zone where the shear of the longshore current is relatively weak, the observed total infragravity velocity to pressure variance ratios (normalized by g/h) are approximately equal to 1, consistent with an infragravity spectrum dominated by gravity (edge and/or leaky) waves. Inside the surf zone where longshore currents are strongly sheared, these normalized ratios are much larger, up to 8 on some occasions, indicating that shear waves contribute as much as 75% of the velocity variance in the infragravity band. Energetic shear waves are confined to the (often) narrow region of strong shear on the seaward side of the longshore current maximum, and their cross-shore structure appears to be insensitive to the beach profile, consistent with the theoretical predictions by Bowen and Holman (1989). In addition, during low-energy incident

wave conditions, infragravity pressure variance decreases with increasing depth qualitatively consistent with the theoretically predicted unshoaling and trapping of gravity waves. However, during high-energy incident wave conditions, the observed infragravity pressure variances are nearly uniform across the surf zone, suggesting strong scattering effects in a wide surf zone (Lippmann, *et al.*, 1997).

IMPACT/APPLICATIONS

Wave breaking is the principal driving force for currents, mean water level changes, and low frequency oscillatory motions within the surf zone, and is also believed to be of order one importance in sediment transport and large scale sand bar evolution. However, simple parameterizations needed to describe the complicated dissipative mechanisms have not generally been guided by observation. Only with recent advances in remote (video, acoustic, microwave, infrared, radar), and *in situ* (void fraction) instrumentation, has quantifying the breaking process been possible, and improvements in the sampling and modeling of wave breaking should lead to much improved understanding the kinematics of wave breaking and its dynamical implications.

TRANSITIONS

Our video analysis techniques developed as part of this research have been used to develop a quantitative aerial video system used in USGS-sponsored regional studies of the North Carolina and southern Californian coastlines (PI's Lippmann, Haines, and Sallenger).

RELATED PROJECTS

Video data analysis of the 1990 Delilah experiment has been examined in collaboration with other ONR funded scientists. Data analysis from the 1994 Duck94 experiment and the 1996 MBBE Experiment continues to be examined collaboratively (PI's Holman, Thornton and Stanton). Image processing techniques needed to quantify the video data continue to be developed, in particular the application of video timestacks (Holman, *et al.*, 1995; Holland, *et al.*, 1995) to the analysis of wave breaking. Technique development has been in close collaboration with Oregon State University (PI Holman), the Naval Research Lab (PI Holland), and the U. S. Geological Survey (PI's Haines and Sallenger). We have also developed an aerial video system for measuring the very-large scale nearshore morphology from time exposure video images spanning about 100 km of coastline (Sponsored by the U. S. Geological Survey, Co-PI's Haines and Sallenger). The system is an expansion of the ONR and USGS sponsored projects to develop video techniques for measuring nearshore morphology and bathymetry (PI Holman).

REFERENCES

Donelan, M., M. S. Longuet-Higgins, and J. S. Turner, Periodicity in whitecaps, *Nature*, 239, 449-450, 1972.

Duncan, J. H., An experimental investigation of breaking waves produced by a towed hydrofoil, *Proc. R. Soc. Lond.*, A377, 331-348, 1981.

Faria, A. F. G., E. B. Thornton, T. P. Stanton, C. V. Soares, and T. C. Lippmann, Vertical profiles of longshore currents and related bed shear stress and bottom roughness, *J. Geophys. Res.*, in press.

Holman, R. A., A. H. Sallenger, T. C. Lippmann, and J. W. Haines, The application of video image processing to the study of nearshore processes, *Oceanography*, 6, 77-85, 1993.

Lippmann, T. C., T. H. C. Herbers, and E. B. Thornton, Gravity and shear wave contributions to nearshore infragravity motions, *J. Physical Oceanogra.*, sub judice).

Lippmann, T. C., T. H. C. Herbers, and E. B. Thornton, Cross-shore variability of infragravity wave pressure and velocities on a barred beach, *Proc. Coastal Dynamics '97*, in press.

Lippmann, T. C., E. B. Thornton, and A. J. H. M. Reniers, Wave stress and longshore currents on barred profiles, *Proc. Coastal Dynamics '95*, ASCE, New York, 401-412, 1996.

Lippmann, T. C., A. H. Brookins, and E. B. Thornton, Wave energy transformation on natural profiles, *Coastal Eng.*, 27, 1-20, 1996.

Lippmann, T. C., and E. B. Thornton, The spatial distribution of wave rollers on a barred beach, *J. Geophys. Res.*, sub judice.

Lippmann, T. C., C. F. Jorgensen, and E. B. Thornton, Wave slopes and breaking distributions in the surf zone, *J. Geophys. Res.*, sub judice.

Lippmann, T. C., R. A. Holman, and A. J. Bowen, Generation of edge waves in shallow water, *J. Geophys. Res.*, 102(C4), 8663-8679, 1997.

Reniers, A. J. H. M., E. B. Thornton, and T. C. Lippmann, Longshore currents over barred beaches, *Proc. Coastal Dynamics '95*, ASCE, New York, 413-424, 1996.

Reniers, A. J. H. M., E. B. Thornton, and T. C. Lippmann, Effects of alongshore non-homogeneities on longshore currents measured in the field, *J .Geophys. Res.*, sub judice.

Svendsen, I. A., Wave heights and set-up in a surf zone, *Coastal Engineering*, 8, 303-329, 1984.